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# ASSESSMENT OF SNOW CRAB (*CHIONOECETES OPILIO*) IN THE SOUTHERN GULF OF ST. LAWRENCE (AREAS 12, 19, 12E AND 12F) TO 2016 AND ADVICE FOR THE 2017 FISHERY

*Snow crab (Chionoecetes opilio).*

*Figure 1. Map of the southern Gulf of St. Lawrence showing the Crab Fishing Areas (CFAs), fishing grounds and management buffer zones (shaded area). Fishing grounds are labeled as follows: 1 Chaleur Bay, 2 Shediac Valley, 3 Orphan Bank, 4 Bradelle Bank, 5 Magdalen Channel, 6 Cape Breton Corridor, 7 Laurentian Channel, and 8 American Bank.*

## Context:

*Snow crab, Chionoecetes opilio, has been commercially exploited in the southern Gulf of St. Lawrence since the mid-1960s. There are four individually managed fishing areas among which Area 12 (Figure 1) is the largest fishery in terms of its fishable surface, number of participants and landings. In Areas 12, 12E and 12F, the fishing season generally starts in April-May as soon as the Gulf is clear of ice and continues into early summer while in Area 19, the fishery opens after June 30 and usually ends in mid-September. The landing of females is prohibited and only hard-shelled males ≥ 95 mm of carapace width are commercially exploited.*

*DFO Gulf Region Fisheries and Aquaculture Management requested an assessment of the resource status in 2016 and catch advice for the 2017 fishery. This document provides an overview of the assessment results and the science advice. Catch rates and other fishery performance indicators are reported. The assessment of the status of the southern Gulf snow crab resource (Areas 12, 19, 12E and 12F) is based on fishery independent trawl surveys that provide indicators of: abundance (commercial biomass), reproductive potential (abundance of mature females), and recruitment. A science peer review meeting was conducted January 25-26, 2017 in Moncton, NB. Participants at the science review were from DFO Science, DFO Fisheries Management, fishing industry, Aboriginal organizations, external reviewers and provincial governments.*

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## SUMMARY


- Snow crab in fishing areas 12, 19, 12E, and 12F comprise a single biological population and the southern Gulf of St. Lawrence stock is considered as one unit for assessment purposes.
- The landings of snow crab from the southern Gulf of St. Lawrence in 2016 were 21,725 t from a revised quota of 21,611 t.
- The resulting exploitation rate of the 2016 fishery in the southern Gulf of St. Lawrence was estimated at 36.9%.
- The 2016 post-fishery survey biomass of commercial-sized adult male crabs was estimated at 99,145 t (95% confidence interval of 87,749 to 111,600 t), an increase of 68.6% from 2015. The available biomass for the 2017 fishery, derived from the 2016 survey, is within the healthy zone of the Precautionary Approach (PA) framework.
- Total commercial biomass in the 2016 survey was composed 75% of new recruitment (74,269 t) and 25% of residual biomass (24,876 t). The recruitment to the commercial biomass increased by 112.6% relative to the previous year.
- Based on the agreed harvest decision rule which has been assessed as compliant with the PA, the point estimate of the biomass in the 2016 survey of 99,145 t corresponds to an exploitation rate of 44.2% giving a Total Allowable Catch (TAC) of 43,822 t for the 2017 fishery.
- The risk analysis indicates that the 2017 TAC derived from the harvest decision rule will result in a near 100% chance of the biomass for the 2018 fishery being above $B_{USR}$ and in the healthy zone of the PA.

Fishery performance in 2016 in Area 12:

- The 2016 landings in Area 12 were 19,499 t from a revised quota of 19,393 t.
- The CPUE (expressed as kg per trap haul (kg/th)) in 2016 (64.0 kg/th) decreased compared to 2015 (67.9 kg/th).
- The incidence of soft-shelled crab in 2016 (5.3%) is comparable to 2015 (4.9%).

Fishery performance in 2016 in Area 19:

- The 2016 landings in Area 19 were 1,701 t from a revised quota of 1,701 t.
- The CPUE in 2016 (142.5 kg/th) is comparable to 2015 (144.8 kg/th).
- The incidence of white-crab increased from 5.5% in 2015 to 8.2% in 2016.

Fishery performance in 2016 in Area 12E:

- In Area 12E, the landings were 144 t from a revised quota of 144 t.
- The CPUE in 2016 (51.5 kg/th) decreased compared to 2015 (65.8 kg/th).
- The incidence of soft-shelled crab in 2016 decreased from 9.8% in 2015 to 1.1% in 2016.

Fishery performance in 2016 in Area 12F:

- The 2016 landings in Area 12F were 381 t from a revised quota of 373 t.
- The CPUE in 2016 (43.9 kg/th) increased compared to 2015 (38.2 kg/th).

- The incidence of soft-shelled crab increased from 3.3% in 2015 to 10.4% in 2016.

# BACKGROUND

## Species Biology

Snow crab (*Chionoecetes opilio*) is a crustacean, like lobster and shrimp, but with a flat, almost circular body and five pairs of spider-like legs. The hard outer shell is periodically shed in a process called molting. After molting, crabs have a soft shell for a period of 8 to 10 months. Soft-shelled crab is defined by shell hardness (<68 durometer units) and includes both new-soft (condition 1) and clean hard-shelled crab (condition 2). The term white-crab is used in the summer fishery of Area 19 because the newly-molted crabs have reached a relatively harder carapace than those observed during the spring fishery (Areas 12, 12E and 12F). White crab is defined by shell hardness <78 durometer units and includes both new soft (condition 1) and clean hard-shelled crab (condition 2).

Unlike lobsters, snow crabs do not continue to molt throughout their lives. Females stop growing when they acquire a wide abdomen for carrying eggs, which occurs at carapace widths (CW) less than 95mm. Males stop growing when they acquire large claws on the first pair of legs, which can occur at CWs between 40 and 150 mm. Females produce eggs that are carried beneath the abdomen for approximately two years in the southern Gulf of St. Lawrence. The eggs hatch in late spring or early summer and the newly-hatched crab larvae spend 12-15 weeks in the water column. At the end of this period, they settle on the bottom. It takes at least 8-9 years (post-settlement) for males to reach legal commercial size.

## Fishery

Until 1994, the snow crab fishery in Area 12 (Figure 1) involved 130 mid-shore crab harvesters from New Brunswick, Québec and Nova Scotia. Since 1997, the PEI coastal fishery, (formerly Areas 25/26) has been integrated into Area 12. In 2003, a portion of the coastal fishery off Cape Breton (formerly Area 18) was also integrated into Area 12. For the purpose of this assessment, Area 12 refers to the management unit that includes snow crab fishing zones 12, 18, 25, and 26 (as defined in regulation) (Figure 1). The number of allocation shares in Area 12 was 249 in 2016.

In 1978, Area 19 (Figure 1) was established for the exclusive use of Cape Breton inshore fish harvesters with vessels less than 13.7 m (45 feet) in length. There were 156 allocation shares in Area 19 in 2016.

Areas 12E and 12F were introduced in 1995 as exploratory fisheries. In 2002, the status of Areas 12E and 12F was changed from exploratory to commercial fishing areas. There were four snow crab allocation shares in Area 12E (from New Brunswick, PEI and Québec) and sixteen snow crab allocation shares in Area 12F (from Nova Scotia and Québec) in 2016.

The minimum legal carapace width for males is 95 mm, females are not harvested and soft-shell and white crab are not targeted by the fishery. Baited traps, constructed of wire or tubular steel, are used to catch crab, mainly on mud or sand-mud bottoms at temperatures ranging from -1 to 4.5°C, and depths ranging from 50 to 280 m. The fishery takes place from spring to early summer in Areas 12, 12E and 12F and after June 30 in Area 19.

Management of these fisheries is based on quotas and effort controls (trap allocations, trap dimensions, and seasons). There are at-sea soft-shelled and white crab catch monitoring protocols which allow for closure of portions of each fishing area when the proportion of the

catch of males of these carapace conditions exceeds 20%. The protocols are in place to maximize the yield and the reproductive potential of the resource.

*Table 1. Number of allocation shares, vessels, traps, revised quotas, opening dates, and dates of last landing of the snow crab fishery by management area in the southern Gulf of St. Lawrence in 2016.*

| Characteristics | Area 12 | Area 12E | Area 12F | Area 19 | Southern Gulf |
|---|---|---|---|---|---|
| Allocation shares [1] | 249 | 4 | 16 | 156 | 425 |
| Number of active vessels | 291 | 4 | 16 | 103 | 414 |
| Total number of traps allowed | 39,666 | 450 | 1,290 | 1,699 | 43,105 |
| Opening date | April 22 | April 22 | April 13 | July 13 | - |
| Date of last landing | July 14 | June 10 | June 27 | August 16 | - |
| Revised quota (t) [2] | 19,393 | 144 | 373 | 1,701 | 21,611 [3] |
| Landings (t) | 19,499 | 144 | 381 | 1,701 | 21,725 |

[1] The number of quota allocations among which the Total Allowable Catch is divided (Source: DFO Administrative List for Snow Crab Areas 12, 12E, 12F, and 19).
[2] For reasons of interannual quota adjustments, reconciliations, and re-distribution of the scientific quota among areas, the revised quota does not necessarily correspond to the TAC in the notice to harvesters.
[3] Quota includes 400 t set aside to finance the trawl survey in 2016 (under Section 10 of the Fisheries Act).

The landings from the southern Gulf of St. Lawrence were low in the 1970s and increased with three periods of high landings: 1981-1986, 1994-1995, and more recently 2002 to 2009 (Figure 2). The peak landing of the entire history was in 2005 at 36,118 t. The landings of snow crab from the southern Gulf of St. Lawrence in 2016 were 21,725 t from a revised quota of 21,611 t.

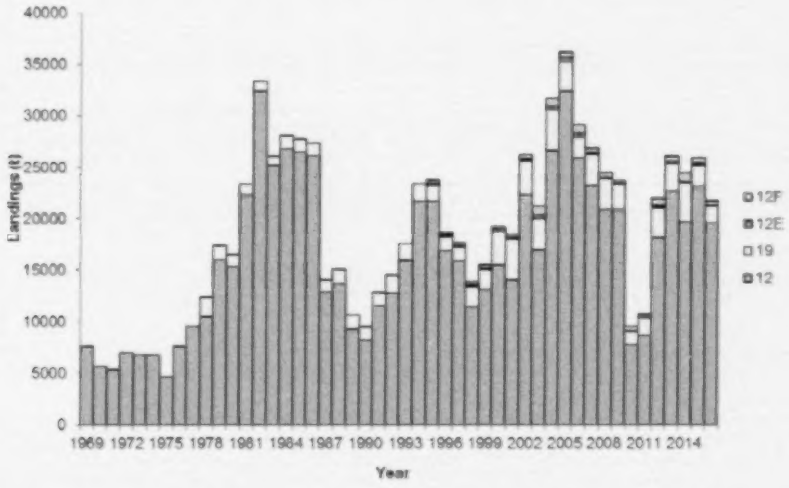


*Figure 2. Landings (tonnes) in the southern Gulf of St. Lawrence snow crab fishery, 1969 to 2016.*

The 2016 fishing season in Area 12 opened on April 22 and the last landings were recorded on July 14 with reported landings of 19,499 t from a revised quota of 19,393 t (Tables 1 and 2; Figure 2). In accordance with the soft-shelled crab protocol, 5 of 323 grids were closed during the 2016 fishing season. The fishing effort estimated from logbooks has varied from 161,148 to 544,454 trap hauls between 1987 and 2016, with the lowest effort in 2010 and the highest effort

in 2002. The fishing effort was 304,624 trap hauls in 2016, a decrease from 2015 (339,912 trap hauls) (Table 2).

*Table 2. Revised quota (2012 to 2016), and landings (tonnes), fishing effort (trap hauls) and catch performance for the snow crab fishery in Area 12, 2008 to 2016.*

| Fishery descriptor | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|
| Revised quota (t) [1] | 20,900 | 20,900 | 7,700 | 8,585 | 18,143 | 22,548 | 19,409 | 23,021 | 19,393 |
| Landings (t) | 20,911 | 20,896 | 7,719 | 8,618 | 18,159 | 22,645 | 19,633 | 23,080 | 19,499 |
| CPUE (kg/trap-haul) [2] | 56.4 | 48.2 | 47.9 | 53.0 | 68.0 | 76.4 | 61.8 | 67.9 | 64.0 |
| Effort (trap hauls) | 370,762 | 433,527 | 161,148 | 162,604 | 267,044 | 296,398 | 317,689 | 339,912 | 304,624 |
| Soft-shelled crab (%) in catches [3] | 3.0 | 5.0 | 6.5 | 6.2 | 3.7 | 2.8 | 4.4 | 4.9 | 5.3 |
| Grids closed (total of 323) | 3 | 78 | 74 | 233 | 7 | 5 | 8 | 41 | 5 |

[1] For reasons of interannual quota adjustments, reconciliations, and re-distribution of the scientific quota among areas, the revised quota does not necessarily correspond to the TAC in the notice to harvesters.
[2] CPUE values are not standardized and do not account for changes in management measures.
[3] The percentage is based on a durometer reading of 68. Catches are defined as male crab of all sizes (commercial >= 95 mm and non-commercial) in traps.

The 2016 fishing season in Area 19 opened on July 13 and the last date of landings was August 16 with reported landings of 1,701 t from a revised quota of 1,701 t (Tables 1 and 3; Figure 2). In accordance with the white crab protocol (shell hardness <72 durometer units), four sectors within Area 19 were closed during the 2016 fishing season. The fishing effort in Area 19 has varied from 11,138 to 56,517 trap hauls between 1987 and 2016, with the lowest effort in 2010 and the highest effort in 2004. The effort in 2016 was 11,937 trap hauls, a decrease from 2015 (Table 3).

*Table 3. Revised quota (2012 to 2016) and landings (tonnes), fishing effort (trap hauls) and catch performance for the snow crab fishery in Area 19, 2008 to 2016.*

| Fishery descriptor | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|
| Revised quota (t) [1] | 3,002 | 2,433 | 1,360 | 1,703 | 2,907 | 2,654 | 3,745 | 2,130 | 1,701 |
| Landings (t) | 2,929 | 2,370 | 1,360 | 1,701 | 2,906 | 2,657 | 3,745 | 2,129 | 1,701 |
| CPUE (kg/trap-haul) [2] | 76.3 | 71.4 | 122.1 | 133.3 | 178.1 | 148.5 | 147.4 | 144.8 | 142.5 |
| Effort (trap hauls) | 38,388 | 33,193 | 11,138 | 12,761 | 16,317 | 17,890 | 25,407 | 14,703 | 11,937 |
| White crab (%) in catches [3] | 9.0 | 11.6 | 6.4 | 11.5 | 4.5 | 3.0 | 1.0 | 5.5 | 8.2 |
| Sectors closed [4] | 4/4 | 9/9 | 4/9 | 0/9 | 0/9 | 0/9 | 0/9 | 2/9 | 4/9 |

[1] For reasons of interannual quota adjustments, reconciliations, and re-distribution of the scientific quota among areas, the revised quota does not necessarily correspond to the TAC in the notice to harvesters.
[2] CPUE values are not standardized and do not account for changes in management measures.
[3] The percentage is based on a durometer reading of 72. Catches are defined as male crab of all sizes (commercial >= 95 mm and non-commercial) in traps.
[4] Total number of sectors was changed from 4 to 9 sectors in 2009.

The 2016 fishing season in Area 12E began on April 22 and the date of last landings was June 10 with reported landings of 144 t from a revised quota of 144 t (Tables 1 and 4; Figure 2). The fishing effort in Area 12E has varied from 1,825 to 10,074 trap hauls between 1995 and 2015, with the lowest effort in 2010 and the highest effort in 2006. The fishing effort in Area 12E decreased from 2,918 trap hauls in 2015 to 2,796 trap hauls in 2016. In accordance with the soft-shelled protocol, no grids within Area 12E were closed during the 2016 fishing season.

*Table 4. Revised quota (2012 to 2016) and landings (tonnes), fishing effort (trap hauls) and catch performance for the snow crab fishery in Area 12E, 2008 to 2016.*

| Fishery descriptor | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|
| Revised quota (t)[1] | 400 | 200 | 67 | 75 | 251 | 204 | 170 | 189 | 144 |
| Landings (t) | 187 | 67 | 50 | 76 | 185 | 204 | 178 | 192 | 144 |
| CPUE (kg/trap-haul)[2] | 20.3 | 14.4 | 27.4 | 31.5 | 32.9 | 40.1 | 47.3 | 65.8 | 51.5 |
| Effort (trap hauls) | 9,232 | 4,653 | 1,825 | 2,413 | 5,623 | 5,097 | 3,765 | 2,918 | 2,796 |
| Soft-shelled crab (%) in catches[3] | 10.1 | 7.8 | 14.7 | 8.4 | 3.3 | 15.9 | 7.8 | 9.8 | 1.1 |
| Grids closed (total of 8) | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

[1] For reasons of interannual quota adjustments, reconciliations, and re-distribution of the scientific quota among areas, the revised quota does not necessarily correspond to the TAC in the notice to harvesters.
[2] CPUE values are not standardized and do not account for changes in management measures.
[3] The percentage is based on a durometer reading of 68. Catches are defined as male crab of all sizes (commercial >= 95 mm and non-commercial) in traps.

In Area 12F, the fishery in 2016 opened on April 13 and the last date of recorded landings was June 27 with reported landings of 381 t from a revised quota of 373 t (Tables 1, 5; Figure 2). The fishing effort in Area 12F has varied from 4,437 to 23,163 trap hauls between 1995 and 2015, with the lowest effort in 2002 and the highest effort in 2014. The fishing effort decreased from 13,351 trap hauls in 2015 to 8,667 trap hauls in 2016. In accordance with the soft-shelled protocol, no sector within Area 12F was closed during the 2016 fishing season.

*Table 5. Revised quota (2012 to 2016) and landings (tonnes), fishing effort (trap hauls) and catch performance for the snow crab fishery in Area 12F, 2008 to 2016.*

| Fishery descriptor | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|
| Revised quota (t)[1] | 585 | 465 | 420 | 314 | 706 | 543 | 906 | 516 | 373 |
| Landings (t) | 431 | 309 | 420 | 313 | 706 | 543 | 882 | 510 | 381 |
| CPUE (kg/trap-haul)[2] | 27.8 | 22.0 | 29.3 | 32.5 | 41.8 | 49.0 | 38.1 | 38.2 | 43.9 |
| Effort (trap hauls) | 15,504 | 14,045 | 14,335 | 9,631 | 16,890 | 11,086 | 23,163 | 13,351 | 8,667 |
| Soft-shelled crab (%) in catches[3] | 7.3 | 11.4 | 8.6 | 2.6 | 9.4 | 2.4 | 1.7 | 3.3 | 10.4 |
| Sectors closed (total of 3) | 3 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |

[1] For reasons of interannual quota adjustments, reconciliations, and re-distribution of the scientific quota among areas, the revised quota does not necessarily correspond to the TAC in the notice to harvesters.
[2] CPUE values are not standardized and do not account for changes in management measures.
[3] The percentage is based on a durometer reading of 68. Catches are defined as male crab of all sizes (commercial >= 95 mm and non-commercial) in traps.

Catch per unit of effort (CPUE) expressed as kg per trap-haul (kg/th) is calculated directly from logbook data as the ratio of total landings (kg) to total effort (trap-hauls). CPUE values are not standardized and do not account for changes in management measures and fishing practices and as a result may not be directly proportional to biomass. In Area 12, the annual mean CPUE decreased in 2016 (64.0 kg/th) compared to 2015 (Table 2; Figure 3). In Area 19, the CPUE (142.5 kg/th) in 2016 is comparable to 2015 (Table 3, Figure 3). The CPUE decreased in Area 12E (51.5 kg/th) in 2016 compared to 2015 while in Area 12F, the CPUE (43.9 kg/th) in 2016 increased compared to 2015 (Tables 4 and 5; Figure 3).

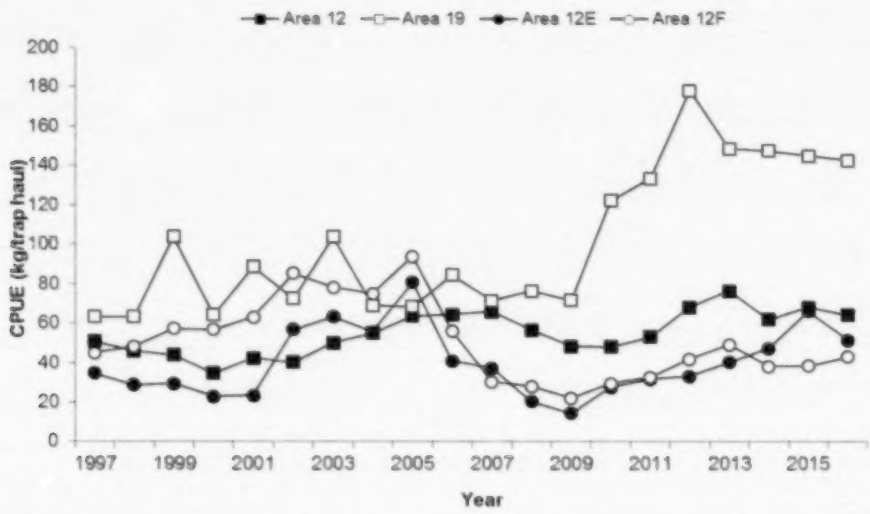


*Figure 3. Catch per unit effort (kg per trap haul) in the southern Gulf of St. Lawrence snow crab fishery, Areas 12, 19, 12E and 12F, based on logbooks, 1997 to 2016.*

The percentage of soft-shelled crab and white crab is calculated using data collected from the at-sea observer program. The incidence of soft-shelled crab and white crab in catches is strongly influenced by the fishing strategy used by harvesters during the season, as well as the hard-shell commercial-sized adult crab abundance in the area.

The percentage of soft-shelled crab in Area 12 in 2016 was 5.3%, comparable to 2015, and has remained low since 2008 (Table 2). In Area 19, the percentage of white crab was 8.2% in 2016, an increase from 2015, and has remained low since 2011 (Table 3). The percentage of soft-shelled crabs in Area 12E in 2016 was 1.1%, a decrease from 2015 (Table 4). In Area 12F, the percentage of soft-shelled crabs in 2016 was 10.4%, an increase from 2015 (Table 5).

## ASSESSMENT

Snow crab in fishing areas 12, 19, 12E, and 12F comprise a single biological population and the southern Gulf of St. Lawrence stock is considered as one unit for assessment purposes.

The survey design and biomass estimation polygon covers the entire area of the southern Gulf of St. Lawrence defined by the 20 to 200 fathoms depth contours (which approximately corresponds to the areal extent of bottom temperatures < 5 °C which are considered favorable for all life stage of snow crab and encompassing the area of the southern Gulf of St. Lawrence biological unit) (Figure 4). The survey spatial sampling design partitioned this area into square grids of 12.7 km x 12.7 km. In 2016, the number of sampling stations remained at 355. The 347 successful sampling stations from the 2015 trawl survey were used as fixed stations as per the recommendations from the 2014 scientific peer review (DFO 2014a) and a new set of 8 sampling stations (the 2 that were abandoned and the 6 sampling stations that were conducted outside their assigned grids in 2015) was generated randomly. A total 354 stations were successfully trawled in 2016; one sampling square had to be abandoned due to failures to successfully trawl the area. The survey was conducted between July 10 and October 4, 2016. All at-sea survey and sampling protocols were identical to previous years.

The survey in 2016 was financed through a collaborative agreement with the fishing industry under Section 10 of the Fisheries Act.

*Figure 4. The survey and estimation polygon of 57,840 km$^2$ used for the 2016 snow crab stock assessment in the southern Gulf of St. Lawrence (all of the coloured areas) and corresponding estimation polygons for the four crab fishing areas (12, 12E, 12F, and 19). The unassigned zone north of areas 12E and 12F (label A) and buffer zones (labels B and C) are also shown.*

## Stock Trends and Current Status in the Southern Gulf

Interpretation of stock status is based on inferences from abundance data from the snow crab trawl surveys conducted during July to October, over the entire area of snow crab distribution in the southern Gulf. The surveys provide estimates of commercial biomass which are comprised of residual biomass (hard-shelled adult males of legal size remaining after the fishery) and recruitment biomass (soft-shelled adult males >= 95 mm CW defined as R-1 that will be available to the fishery the following fishing season). The snow crab trawl survey also provides indices of future male recruitment to the fishery (pre-recruits defined as R-4, R-3 and R-2). The pre-recruits R-4, R-3 and R-2 represent adolescent male crabs with a carapace width range of 56-68, 69-83, and larger than 83 mm, respectively. A portion of these crabs could be available to the fishery in 4, 3 and 2 years, respectively. An index of abundance of small male crab (34-44 mm CW) is also presented as an indicator of potential long-term recruitment. It takes at least six years for these small male crabs to reach the commercial size of 95 mm CW.

Spawning stock abundance consists of females (pubescent and mature). The term pubescent refers to females that will molt to maturity and mate the following year and become primiparous females (first brood). The term 'multiparous' refers to females which are carrying a brood for the second time or more. The term 'mature females', includes primiparous and multiparous females.

The biomass of commercial-sized adult males in the southern Gulf of St. Lawrence from the 2016 trawl survey was estimated at 99,145 t (95% confidence interval (C.I.) range of 87,749 t to 111,600 t; Table 6; Figure 5). The estimated commercial biomass in the southern Gulf increased by 68.6% relative to the 2015 estimate (58,808 t; 95% C.I. 52,754 t to 65,466 t).

The recruitment to the fishery at the time of the 2016 survey was 74,269 t (95% C.I. 66,381 t to 82,807 t), comprising 75% of the commercial biomass (Table 6; Figure 5). The recruitment to the fishery in 2016 increased by 112.6% compared to the 2015 estimate. The residual biomass (carapace conditions 3 to 5) of commercial-sized adult male crab after the 2016 fishery was estimated at 24,876 t (95% C.I. 21,369 t to 28,793 t), a comparable level to the 2015 estimate (Table 6; Figure 5).

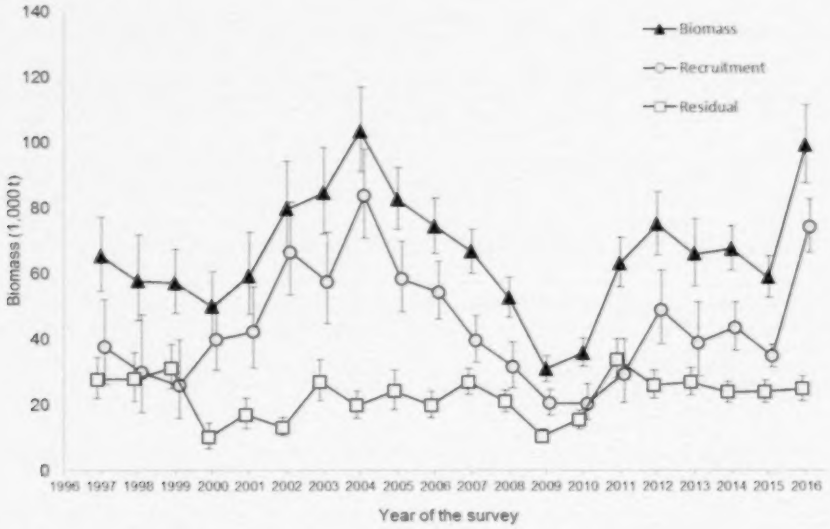


*Figure 5. Total commercial biomass, recruitment commercial biomass, and residual commercial biomass (in 1,000 tonnes; means with 95% confidence intervals) in the southern Gulf of St. Lawrence, 1997 to 2016.*

A second fishery independent survey of the southern Gulf of St. Lawrence is used to provide an index of biomass of commercial-sized adult male crab. The multi-species research vessel bottom trawl survey (RV), a stratified random design, has been conducted annually in September since the early 1970's although the estimation of commercial-sized adult male crab biomass is available only since 2001.

Over the available time series, the September multi-species bottom trawl survey index shows generally similar trends (within the estimation precisions of the surveys) for commercial adult male snow crab biomass between 2001 and 2016 as do the estimates from the dedicated snow crab trawl survey (Figure 6). The RV survey index indicated an important increase in the biomass of commercial-sized adult male snow crab in 2016, similar to what was estimated from the dedicated snow crab survey data.

In the 2016 trawl survey, geographic concentrations of commercial-sized adult males were located in Bradelle Bank, in Shediac valley, in Chaleur Bay, in the southern part of the Magdalen Channel and in the southeastern part of the sGSL (Figure 7). The spatial distributions of commercial-sized adult males have varied annually during increasing and decreasing phases of the commercial biomass (Figure 8).

*Table 6. Total commercial, recruitment, and residual biomass (in tonnes; means with 95 % confidence intervals) of commercial-sized adult male crabs (>= 95 mm carapace width) in the southern Gulf of St. Lawrence, 2007 to 2016.*

| Year of the survey | Commercial Biomass (t) | Recruitment Biomass (t) | Residual Biomass (t) |
|---|---|---|---|
| 2007 | 66,660<br>60,183-73,638 | 39,635<br>33,089-47,092 | 27,025<br>23,354-31,106 |
| 2008 | 52,564<br>46,658-59,006 | 31,555 •<br>25,181-39,048 | 21,010<br>17,960-24,426 |
| 2009 | 30,920<br>27,237-34,959 | 20,520<br>16,848-24,754 | 10,399<br>8,560-12,516 |
| 2010 | 35,795<br>31,681-40,291 | 20,351<br>15,360-26,450 | 15,444<br>12,859- 18,394 |
| 2011 | 63,162<br>55,965-71,022 | 29,394<br>20,909-40,190 | 33,768<br>28,297-39,985 |
| 2012 | 74,997<br>65,822-85,086 | 48,969<br>38,667-61,173 | 26,028<br>21,950-30,641 |
| 2013 | 65,868<br>56,283-76,610 | 38,981<br>28,969-51,346 | 26,886<br>22,909-31,352 |
| 2014 | 67,534<br>60,994-74,579 | 43,630<br>36,774-51,388 | 23,897<br>20,927-27,168 |
| 2015 | 58,808<br>52,754-65,466 | 34,929<br>31,670-38,429 | 24,022<br>20,761-27,647 |
| 2016 | 99,145<br>87,749-111,600 | 74,269<br>66,381-82,807 | 24,876<br>21,369-28,793 |

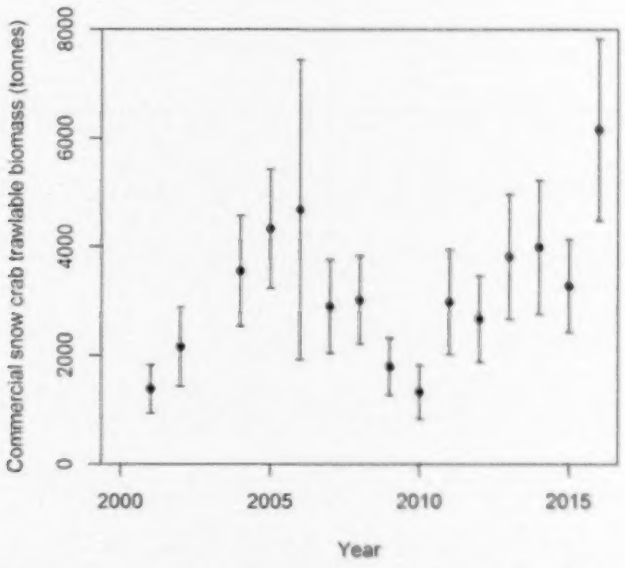


*Figure 6. Index of trawlable biomass (in tonnes; means and 95% confidence intervals) of adult male snow crab ≥ 95 mm carapace width in the September RV survey for 2001 to 2016 excluding 2003, based on a geographic area comparable to that used for the current snow crab assessment.*

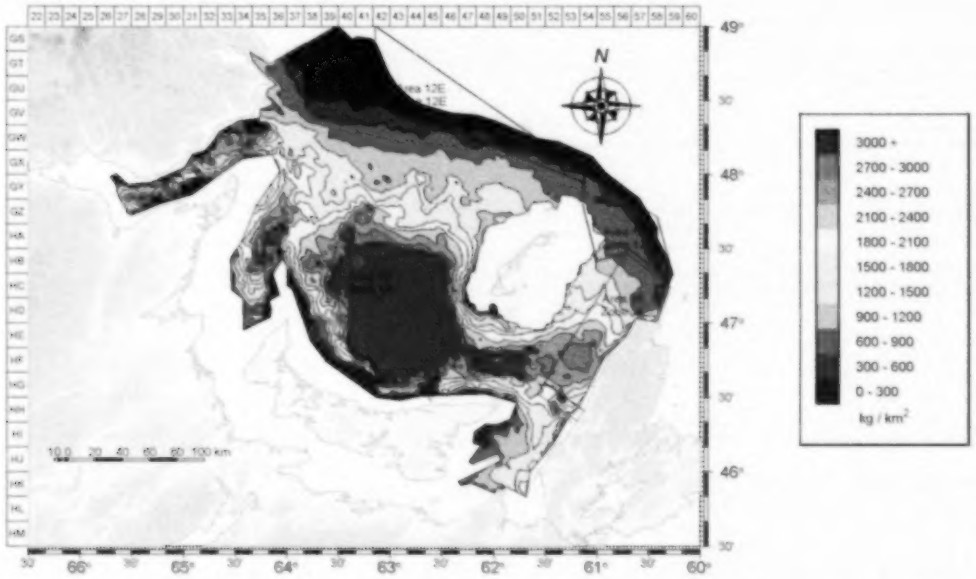


*Figure 7. Density (kg per km2) contours of commercial-sized adult male crab (≥95 mm CW) in the southern Gulf of St. Lawrence in 2016, based on the snow crab trawl survey.*

*Figure 8. Density (kg per km2) contours of commercial-sized adult male crab (≥95 mm CW) in the southern Gulf of St. Lawrence, 2007 to 2015.*

The exploitation rate in the southern Gulf of St. Lawrence is calculated as the ratio between the catch of the fishery in the year of the assessment and the commercial biomass estimated from the trawl survey in the previous year. The exploitation rates varied between 21% and 45% from 1998 to 2016 (Figure 9). In 2016, the exploitation rate was 36.9%.

Total mortality is calculated as residual biomass estimated from the survey in the year of the assessment divided by the biomass available to the fishery as estimated in the previous year's survey. In 2016, total mortality was estimated at 57.7% (Figure 9). The total mortality has varied between 45.8% and 82.5% since 1997, except for 2011 when it was estimated at 5.6% (Figure 9).

Over the time series, the estimated commercial biomass from the survey was 28.8% higher than the sum of the residual biomass and the landings of the following year. This difference (termed non-fishing directed mortality) and the associated inter-annual variability could be attributed to a number of factors including misattribution of recruitment and residual groups, variability in survey estimates, natural mortality, non-directed fishery induced mortalities, as well as crab movement in and out of the sampling area.

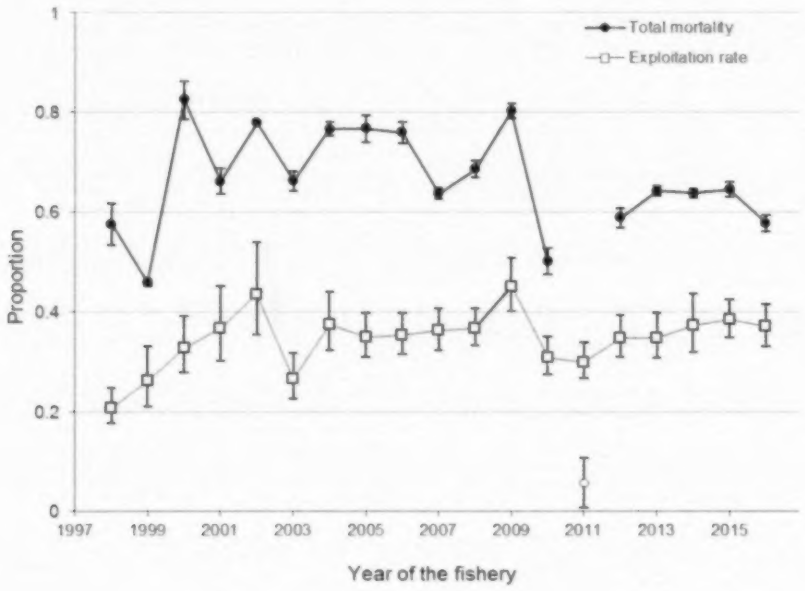


*Figure 9. Exploitation rates (means and 95% confidence intervals) by the fishery and total mortality of commercial-sized adult male snow crab in the southern Gulf of St. Lawrence, 1997 to 2016. The 2011 total mortality point is isolated from the series due to uncertainties.*

As requested by DFO Fisheries and Aquaculture Management, the 2016 commercial biomass estimates in snow crab fishing areas (12, 19, 12E and 12F), two buffer zones (between Areas 12F and 19, between Areas 12 and 19) and the unassigned zone (north of Areas 12E and 12F), as shown in Figure 4, are summarized in Table 7. The majority of biomass was found in Area 12, followed by Area 19, 12F, 12E, buffer zones, and the unassigned zone (Table 7).

*Table 7. Estimates of commercial biomass (in tonnes; means and 95% confidence intervals) in 2016 for the southern Gulf of St. Lawrence estimation polygon of 57,840 km$^2$ and for each of the snow crab fishing areas 12, 19, 12E, 12F, the buffer zones, and the unassigned zone. Labels refer to those in Figure 4.*

| Area | Surface area (km$^2$) | Commercial biomass (t) | |
|---|---|---|---|
| | | Mean | 95% confidence intervals |
| Southern Gulf [1] | 57,840 | 99,145 | 87,749 – 111,600 |
| Area 12 | 48,028 | 89,878 | 79,842 – 100,817 |
| Area 19 | 3,833 | 6,667 | 4,635 – 9,293 |
| Area 12E | 2,443 | 441 | 18 – 2,331 |
| Area 12F | 2,438 | 1,469 | 381 – 3,964 |
| Subtotal of crab fishing areas | 56,742 | 98,455 | na |
| Unassigned zone above 12E and 12F (label A) | 674 | 28 | 0 – 78 |
| Buffer zone 19 / 12F (label B) | 112 | 79 | 0 - 214 |
| Buffer zone 12 / 19(label C) | 310 | 563 | 119 – 1,007 |
| Total of all individual area estimates [1] | 57,838 | 99,125 | na |

[1] Small difference in the sum of all individual area estimates compared to the southern Gulf estimates are due to rounding of intermediate calculation precisions.

Based on abundances of adolescent males of R-2, R-3 and R-4 from recent surveys, the predicted recruitment of commercial-sized adult male crab for the 2017 survey, available for the 2018 fishery, was estimated at 46,200 t (95% C.I. 31,400 to 64,230 t) (Figures 10 and 11).

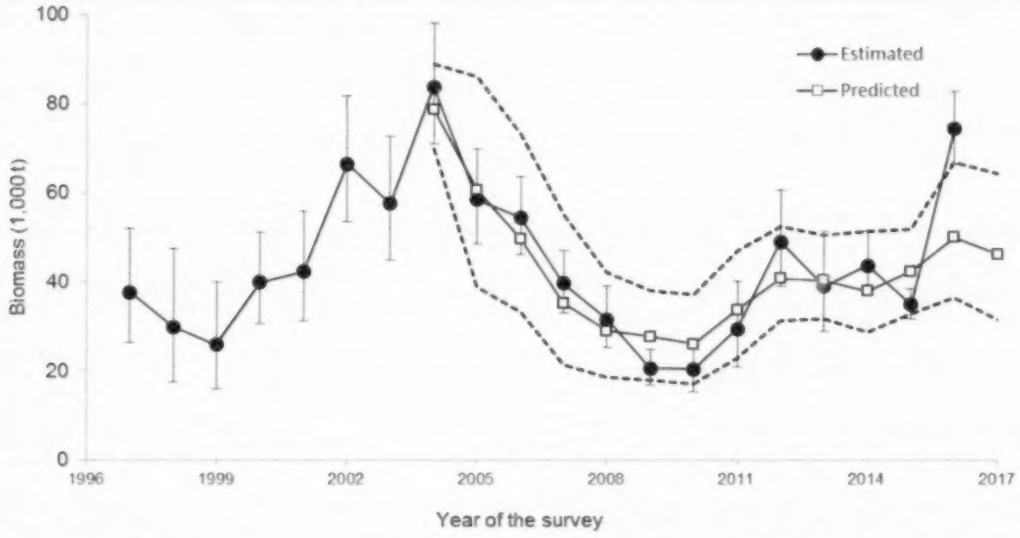


*Figure 10. Estimated (black circle symbols are the means with 95% confidence interval vertical bars) and predicted (open square symbols are the means with the 95% confidence interval bands as dashed lines) biomasses of R-1 (adult male crabs >= 95 mm carapace width of carapace condition 1 and 2) snow crab in the year of the survey, 1997 to 2016. The predicted abundances are based on a relationship to the estimated abundances of R-2 (adolescent male crab larger than 83 mm CW) in the previous year. Prediction of R-1 biomass for 2017 is based on abundances of R-2 estimated in 2016 and shown in Figure 11.*

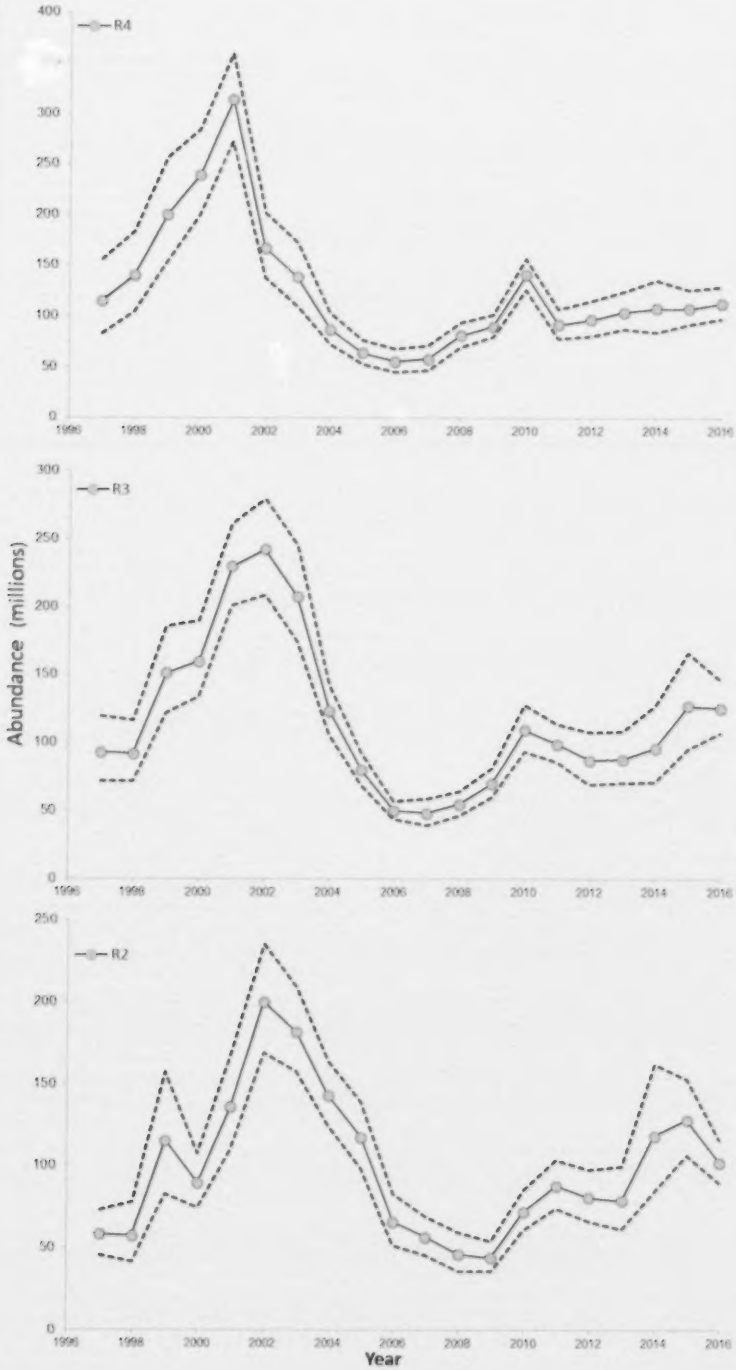


*Figure 11. Estimated abundances (in millions; means and 95% confidence intervals) of R-4 (upper panel), R-3 (middle panel) and R-2 (lower panel) adolescent male crabs in the southern Gulf of St. Lawrence for the survey years 1997 to 2016.*

The index of abundance of small male crab (34-44 mm CW) from the trawl survey in 2016 increased compared to the index estimated in 2015 (Figure 12).

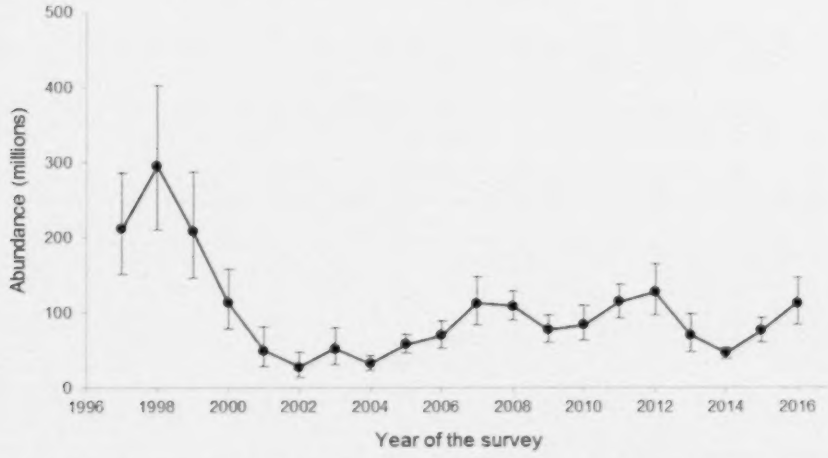


*Figure 12. Index of abundance (in millions; means with 95% confidence intervals) of small male crab of 34 to 44 mm CW, based on the trawl surveys conducted in the southern Gulf of St. Lawrence, 1997 to 2016.*

## Reproduction

The abundance of mature females is showing an increasing trend since the low value observed in 2006 (Figure 13). The increase of pubescent females observed in the 2016 survey suggests that the abundance of mature females may increase in the coming years (Figure 13).

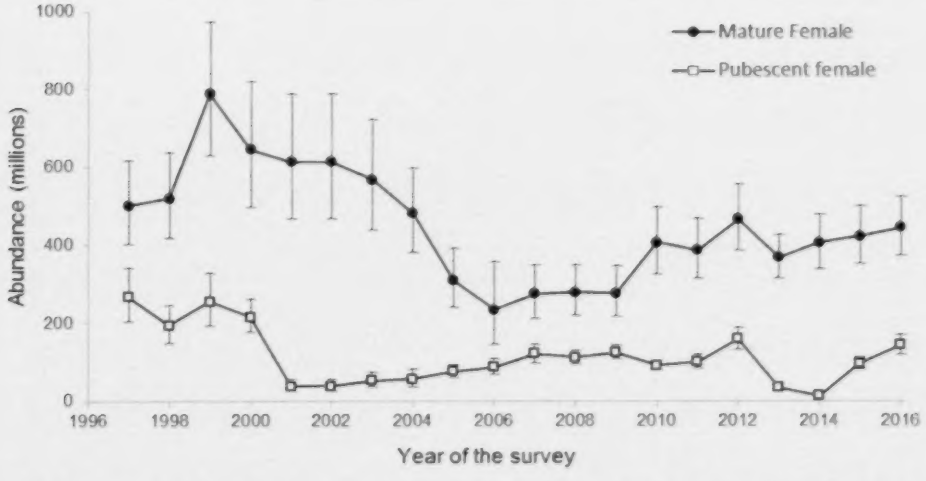


*Figure 13. Estimated abundances (in millions; means and 95% confidence intervals) of mature female (black circle symbols) and pubescent females (open square symbols) in the southern Gulf of St. Lawrence based on the trawl surveys from 1997 to 2016.*

## Environmental Considerations

In September 2016, the near-bottom mean water temperature was near the mean value of the period 1981 to 2010 in most of the central portion of Area 12. The bottom waters around

Magdalen Island, Area 12E, Area 12F and the northwestern portion of the southern Gulf of St. Lawrence (channels connecting the slope of the Laurentian Channel to the Magdalen Shallows) were significantly warmer than normal. Temperatures in Area 19 also were warmer than average. There was a band of bottom water along the slope of Chaleur Bay stretching down to north shore of PEI that was cooler than average. Most of the snow crab fishing grounds slightly cooled down in 2016 compared to 2015, except for deeper channels and the slope leading to the Laurentian Channel where the water was significantly warmer. The snow crab habitat index (bottom area with temperatures from -1 to 3°C) was very close to the average (1% below) in 2016 and increased by 4% from 2015 (Figure 14). The mean temperature (1.0°C) within the defined snow crab habitat area index (-1 to 3°C) in 2016 increased by about 0.2°C compared to 2015 (0.8°C) (Figure 14). The mean temperature was at the highest of the 45 year time series in 2012, decreased in 2013, remained close to the long-term mean in 2014 and 2015 but rose significantly above the mean in 2016.

Snow crab is a stenothermic species with a preference for colder water temperatures. A temperature regime shift from cold to warm may have impacts on population dynamics of snow crab such as shortened reproductive cycles, increased per capita fecundity, and increased size at maturity, greater natural mortality, spatial contraction of habitat, and skewed sex ratio for reproduction. The stock may be more vulnerable to commercial fishing pressure under climate-driven changes resulting in increasing temperatures. Furthermore, the outcome of climate change on snow crab population dynamics can be relatively abrupt and even detrimental, and the direction of the effect may be difficult to predict (Sainte-Marie et al. 2008).

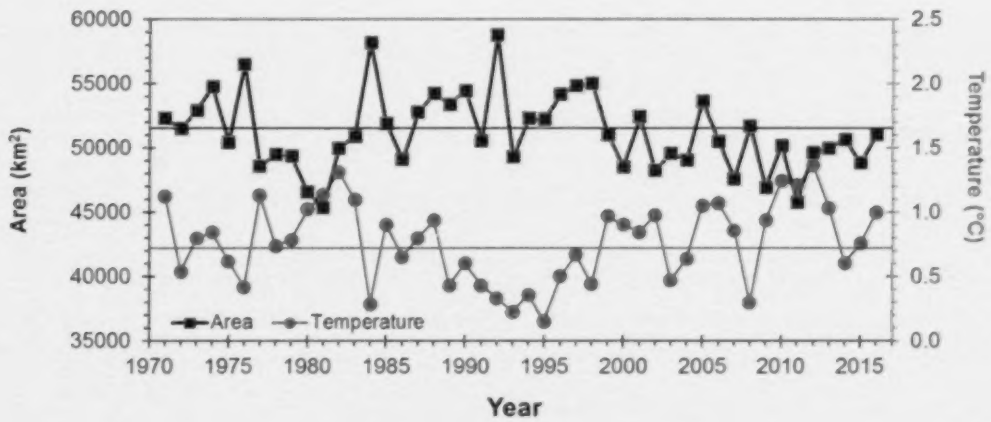


*Figure 14. Snow crab temperature habitat area index (km²) that encompasses water temperatures of -1 to 3 °C (upper panel) and the mean temperature (°C) within the temperature area index (lower panel) in the southern Gulf of St. Lawrence, 1971 to 2016.*

## Sources of Uncertainty

There have been changes in snow crab survey vessel over the 1997 to 2016 assessment period, including a change in vessel in 2013 from the vessel which had been used during 2003 to 2012. There have never been any comparative experiments to assess if there were changes in catchability between vessels. Changes in survey catch rates over time may not accurately reflect changes in stock size if survey vessels have different catchabilities.

The unstandardized catch per unit effort from the fishery correlates weakly with the estimated biomass from the assessment. This results in differences in perception of stock abundance from

the fishing industry observations (catch per unit of effort variations within season and between years) from those of the assessment. A spatially and temporally designed analysis of the CPUE data and densities of crab from the survey are still ongoing.

The distribution of snow crab within the southern Gulf of St. Lawrence and the proportions of the estimated abundance of commercial sized adult male crab in each of the management areas show high inter-annual variations. The factors determining these relative distributions are not known but are seemingly related to movements of crab and recruitment pulses within and in the boundary areas outside of the southern Gulf rather than survival or exploitation. Changes in the environment, particularly the size of the Cold Intermediate Layer, are likely important factors but the influence of these factors on the movements and recruitment dynamics of crab is presently not known.

The estimated recruitment from the 2016 survey was much higher and outside the confidence interval ranges compared to the value predicted from the abundance of R-2 in 2015. Predicting recruitment is uncertain because of a number of factors including variations in mortality, growth among stages and the variation in the proportion of pre-recruits that molt in any given year. In 2015, there was a high abundance and proportion of skip molters (crab that had not molted over the year) in the R-2 stage compared to previous years and it appears that this high abundance of skip molters resulted in a much higher molting rate and/or survival rate to the recruitment stage. Research on the factors that lead to skip molting in snow crab, either through density dependence (competition for resources) or annual variations in food availability, for example, should be undertaken.

Temperature in the southern Gulf varies annually. These changes in temperature can affect a number of life history processes including molting and growth, reproduction, and larval development. The impacts of changing conditions on the snow crab stock are uncertain but this warrants further study.

## CONCLUSIONS AND ADVICE

Within the Precautionary Approach (PA) framework (DFO 2009), the Limit Reference Point for biomass ($B_{lim}$) defines the critical / cautious zones and an upper stock reference ($B_{USR}$) delimits the cautious / healthy zones on the stock status axis. The upper stock reference point ($B_{USR}$) is 41,400 t of commercial-sized adult males of all carapace conditions as estimated from the trawl survey (DFO 2012b). Commercial sized adult male crabs of all carapace conditions are available for the fishery in the year following the trawl survey. The biomass limit reference point ($B_{lim}$) value is 10,000 t (DFO 2012b). The biomass limit reference point was chosen as the lowest biomass of hard shelled commercial sized adult males which produced good recruitment rates of small male crabs of 34-44 mm CW (referred to as Instar VIII) (DFO 2010). The removal reference point ($F_{lim}$) is 34.6% (DFO 2012b). The southern Gulf of St. Lawrence commercial biomass estimate from the trawl survey is used for evaluating catch options relative to the defined reference points.

The trajectory of stock abundance (biomass of commercial-sized adult male crab as estimated from the trawl survey in the year before the fishery) versus exploitation rate in the fishery year for snow crab from the southern Gulf of St. Lawrence is shown in Figure 15. The commercial biomass has varied between 30,920 t and 103,429 t during 1998 to 2016. Over this same period, exploitation rates have varied between 20.8% and 45.0%. The estimated biomass from the 2016 snow crab survey, which would be available to the fishery in 2017, is 99,145 t (95% CI 87,749 – 111,600 t). The 2016 survey biomass estimate is in the healthy zone.

Harvest decision rules that conform to the PA have been developed (DFO 2014b). These PA compliant harvest decision rules include rules for which the exploitation rate exceeds $F_{lim}$ when

the stock is in the healthy zone (DFO 2014b). The Snow Crab Advisory Committee agreed on the proportional harvest decision rule (variant 4 in DFO 2014b, Figure 16) to derive the exploitation rate and the TAC based on the estimated biomass from the southern Gulf of St. Lawrence snow crab survey. This decision rule and the corresponding estimated commercial biomass from the 2016 survey of 99,145 t, results in a selected exploitation rate of 44.2% and corresponding to a TAC of 43,822 t for the 2017 fishery (Figure 16).

A risk analysis was developed for the decision rule TAC and relative to other catch levels in 2017 (Table 8). The risk analysis indicates that the TAC derived from the harvest decision rule will result in a near zero chance of the residual biomass after the fishery being less than $B_{lim}$ and a near 100% chance of the biomass for the next year's fishery being above $B_{USR}$ and in the healthy zone of the PA (Table 8). The risk analysis also provides predictions of the commercial biomass in the 2017 survey, assuming the corresponding catch level is taken in 2017. At the decision rule TAC value of 43,822 t for the 2017 fishery, the commercial biomass predicted for the 2017 post-fishery survey and for the 2018 fishery, is 77,700 t, with a 95% confidence interval range of 61,950 to 93,600 t, a decrease compared to the 2016 survey estimates, but in the healthy zone of the PA framework.

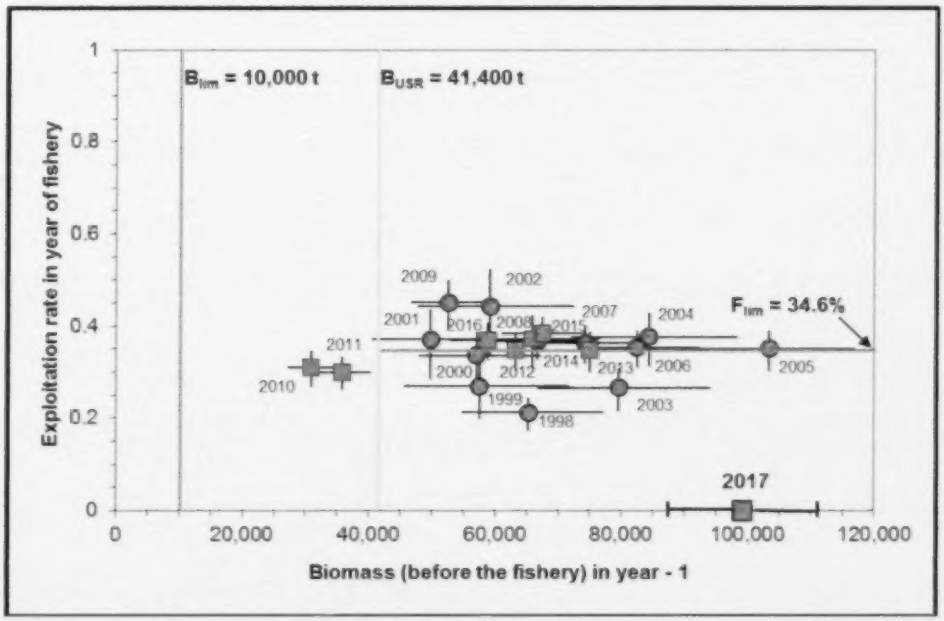


*Figure 15. Trajectory of stock abundance (biomass of commercial-sized adult male crab as estimated from the trawl survey in year before the fishery) versus exploitation rate in the fishery year for snow crab from the southern Gulf of St. Lawrence. Year of the fishery is labeled on the figure. Error bars are 95% confidence intervals. White circle symbols are biomass and exploitation rate levels used to define the reference points. The grey squares are the years when the reference points were used within the PA to decide on the fishery quota. The biomass estimate available for the 2017 fishery (with 95% confidence interval) is also shown.*

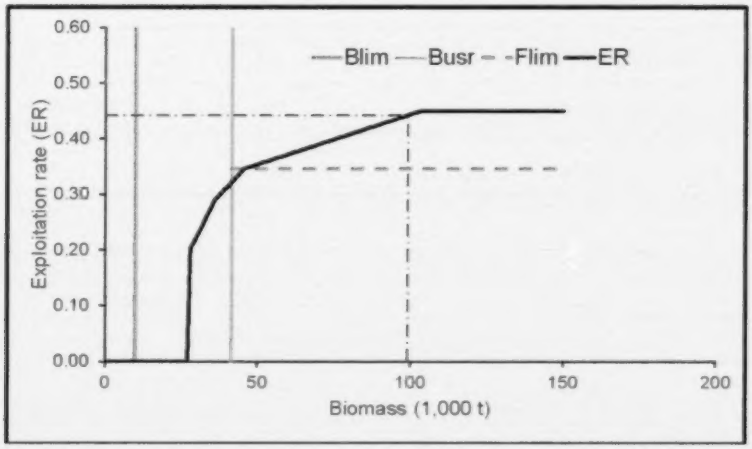


*Figure 16. Harvest decision rule (solid black line; proportional variant 4; DFO 2014b) for the southern Gulf of St. Lawrence snow crab fishery and corresponding exploitation rate (0.442) for the 2017 fishery resulting from the commercial biomass estimate of 99,145 t (dashed-dotted line).*

*Table 8. Risk analysis of catch options in 2017 for the southern Gulf of St. Lawrence snow crab fishery showing probabilities of the hard-shell commercial-sized adult male remaining biomass falling below $B_{lim}$, and of the total commercial-sized adult male biomass being equal to or above $B_{USR}$ post-fishery in 2017. The catch level of 43,822 t based on the agreed harvest decision rule is highlighted in the table. Also shown is the predicted (mean; 95% confidence interval range) commercial biomass from the 2017 survey assuming each corresponding catch level is fished.*

| | Probability | | |
|---|---|---|---|
| Catch level (t) | < $B_{lim}$ (10,000 t) | >= $B_{USR}$ (41,400 t) | Expected biomass for the 2017 post-fishery survey |
| 40,000 | 0 | 1 | 81,500 (65,750-97,400) |
| 41,000 | 0 | 1 | 80,500 (64,750-96,400) |
| 42,000 | 0 | 1 | 79,500 (63,750-95,400) |
| 43,000 | 0 | 1 | 78,500 (62,750-94,400) |
| 43,500 | 0 | 1 | 78,000 (62,250-93,900) |
| 43,822 | 0 | 1 | 77,700 (61,950-93,600) |
| 44,000 | 0 | 1 | 77,500 (61,750-93,400) |
| 45,000 | 0 | 1 | 76,500 (60,750-92,400) |
| 46,000 | 0 | 1 | 75,500 (59,750-91,400) |
| 47,000 | 0 | 1 | 74,500 (58,750-90,400) |
| 48,000 | 0 | 1 | 73,500 (57,750-89,400) |
| 49,000 | 0 | 1 | 72,500 (56,750-88,400) |
| 50,000 | 0 | 1 | 71,500 (55,750-87,400) |
| 65,130 | 0.5 | 1 | 56,370 (40,620-72,270) |
| 80,140 | 1 | 0.50 | 41,360 (25,610-57,260) |

## SOURCES OF INFORMATION

This Science Advisory Report is from the Fisheries and Oceans Canada, Canadian Science Advisory Secretariat, regional advisory meeting of January 25-26, 2017 on the Stock assessment of the southern Gulf of St. Lawrence snow crab stock to 2016 and catch advice for the 2017 fishery. Additional publications from this process will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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*Aussi disponible en français :*

*MPO. 2017. Évaluation du crabe des neiges (Chionoecetes opilio) du sud du golfe du Saint-Laurent (zones 12, 19, 12E et 12F) jusqu'en 2016 et avis pour la pêche de 2017. Secr. can. de consult. Sci. du MPO. Avis sci. 2017/004.*